清華大學 Tsinghua University

Intelligent Microwave Circuit and System Lab

5G大规模MIMO高效线性功放MMIC

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智能微波电路与系统实验室

2019年4月2日

汇报内容

一、5G大规模MIMO功放需求

二、Sub-6GHz Doherty功放设计

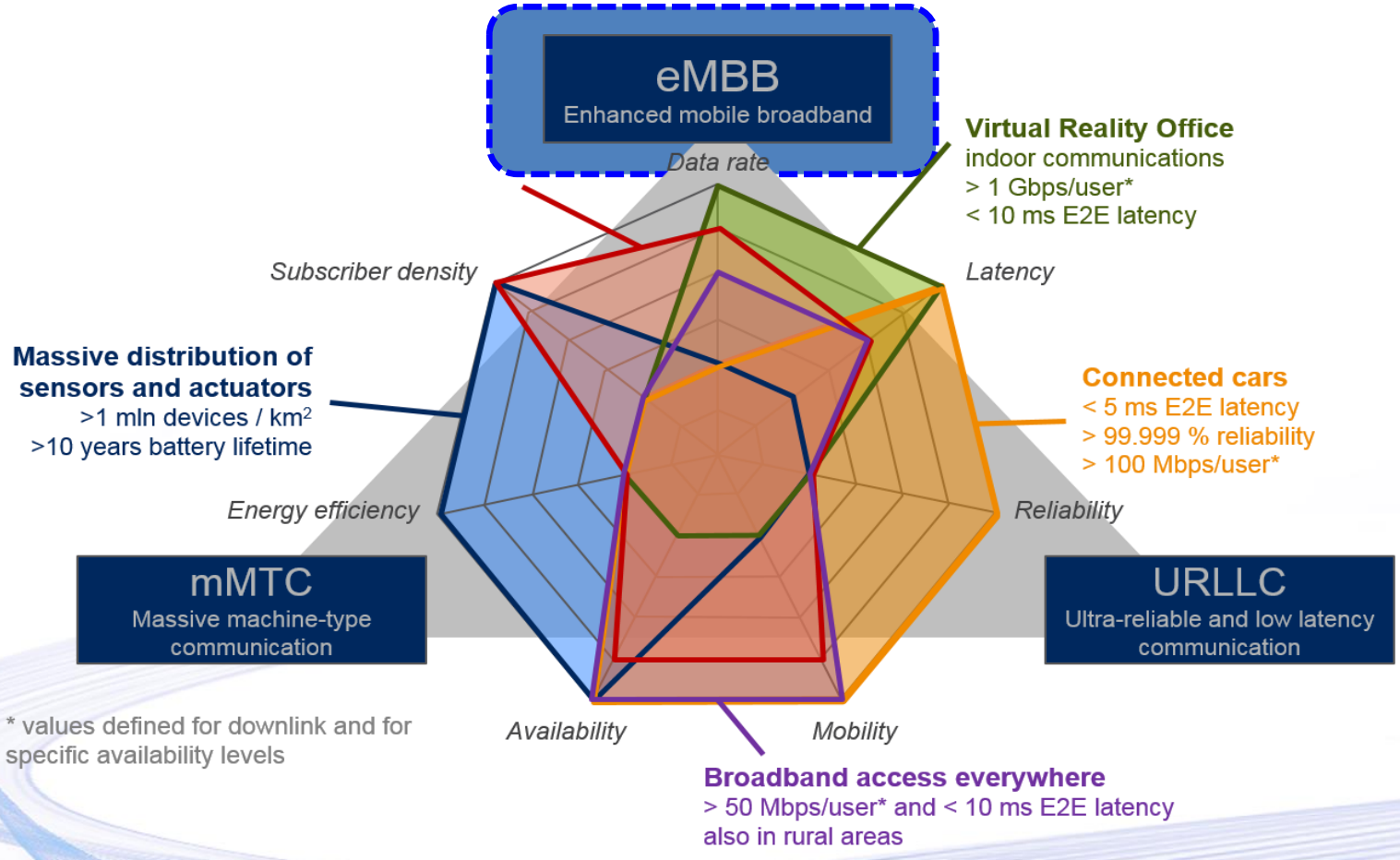
三、mmWave Doherty功放设计

四、大规模MIMO功放线性化

五、总结与展望

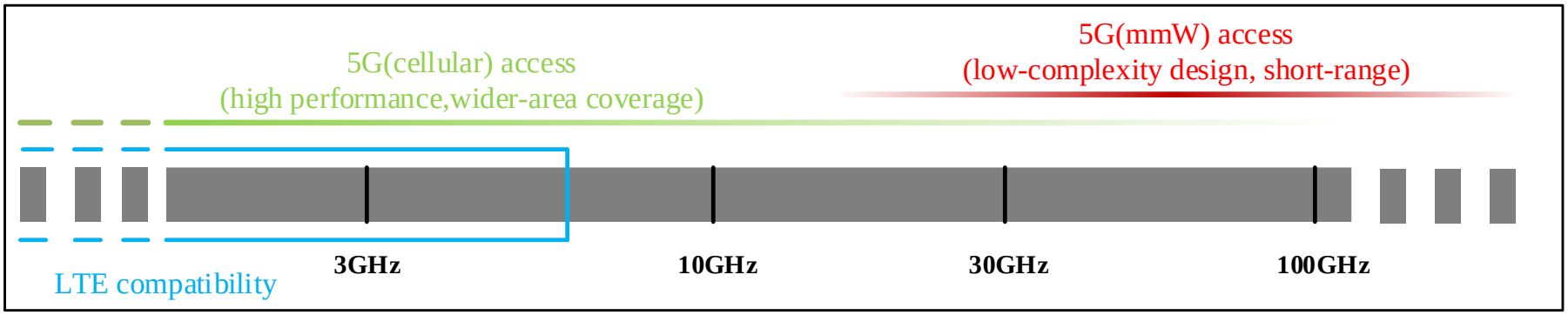
5G应用场景

- ITU IMT-2020



5G频谱规划

5G频谱提供了前所未有通信带宽



公开征求对第五代国际移动通信系统（IMT-2020）使用3300-3600MHz和4800-5000MHz频段的意见

状态：未发布 结束日期：2017-07-07

发表我的意见

为适应和促进IMT-2020在我国的应用和发展，根据《中华人民共和国无线电频率划分规定》，参考国际电联《无线电规则》和相关标准，结合我国频率使用的实际情况，工业和信息化部研究起草了《工业和信息化部关于第五代国际移动通信系统（IMT-2020）使用3300-3600MHz和4800-5000MHz频段相关事宜的通知（征求意见稿）》（具体见附件），现公开征求意见。请于2017年7月7日前反馈意见。

联系人：工业和信息化部无线电管理局
电话：010-68206251
传真：010-68206220
地址：北京市西城区西长安街13号工业和信息化部无线电管理局（邮编：100804）。请在信封上注明“频率规划征求意见”。

附件

Verizon to Launch Fixed Wireless ‘5G’ at 28 GHz; Are They Shooting Too High?

February 23, 2017

BY J. SHARPE SMITH

Senior Editor, AGL eDigest

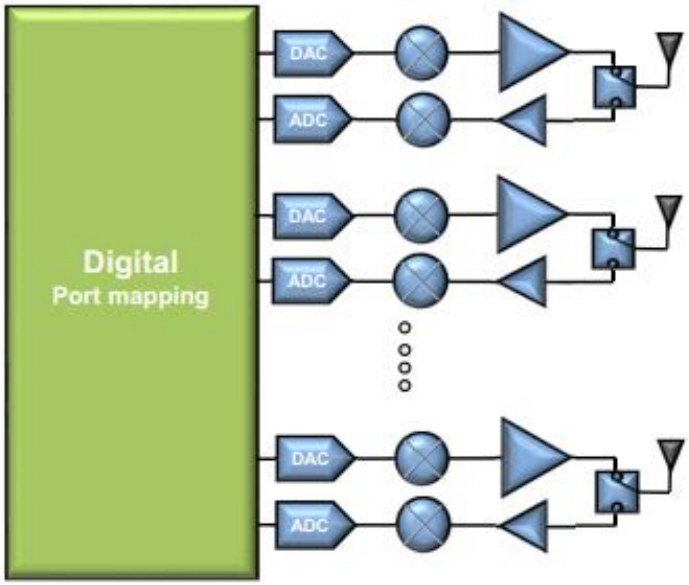
Verizon has announced its plans a large fixed “5G” pilot in the 28 GHz band providing high-speed, low-latency pre-commercial services to select customers in 11 markets. But some in the industry wonder if it is the right service for those frequencies.

Jaime Fink, co-founder of Mimosa Networks, said that the 28 GHz band may not be viable for fixed wireless 5G. In contrast with Verizon, Mimosa’s fixed wireless technology resides in the spectrum below 6 GHz.

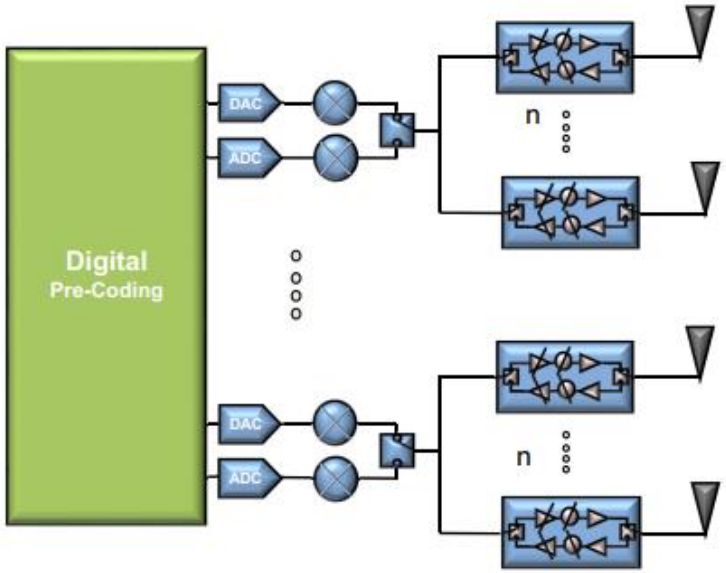
“Delivering mmWave broadband connectivity in non-line-of-sight (NLOS) environments, such as suburban and urban areas, is extremely problematic over the last quarter mile, because of foliage and solid constructions,” he said. “Rather than using the challenging, unproven mmWave channels for 5G, the industry should use the sub-6 GHz spectrum bands, which have incredible propagation characteristics through foliage and construction materials.”

Massive MIMO发射机架构

3.5GHz数字波束成形



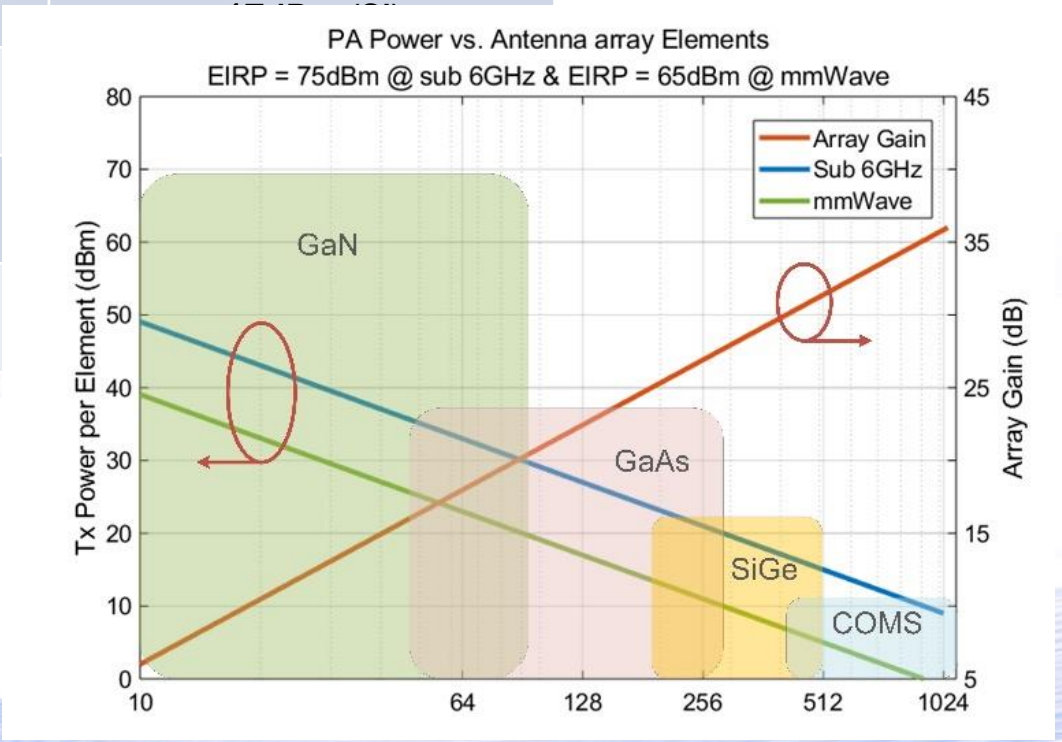
毫米波混合波束成形



数字波束成形	混合波束成形
数字加权	数字与模拟加权
大功率、高复杂度	较小功率、复杂度较低
支持多数据流、容量大	数据流较少
灵活性高	性能与成本折中

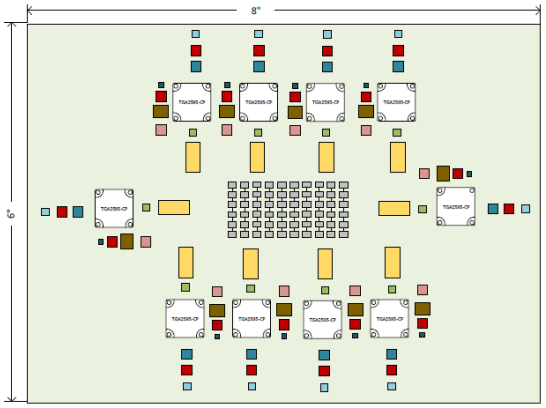
5G大规模MIMO功放需求分析

技术指标	Sub-6G	mmWave
工作频率	3.4~3.8GHz 4.8~5.0GHz	24.75~27.5GHz 37~42.5GHz
信号带宽	>200MHz	>800MHz
输出功率	>43dBm	>25dBm (III-V)
平均效率	>40%	
ACPR	<-45dBc	
EVM	<5% (64QAM) <3% (256QAM)	



大规模MIMO发射机功耗分析

- 功放效率对发射机功耗降低有显著影响



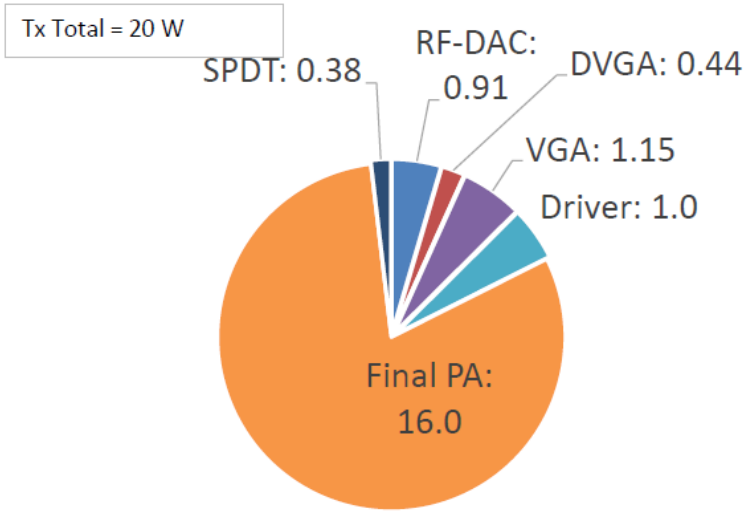
10T10R: TGA2595-CP

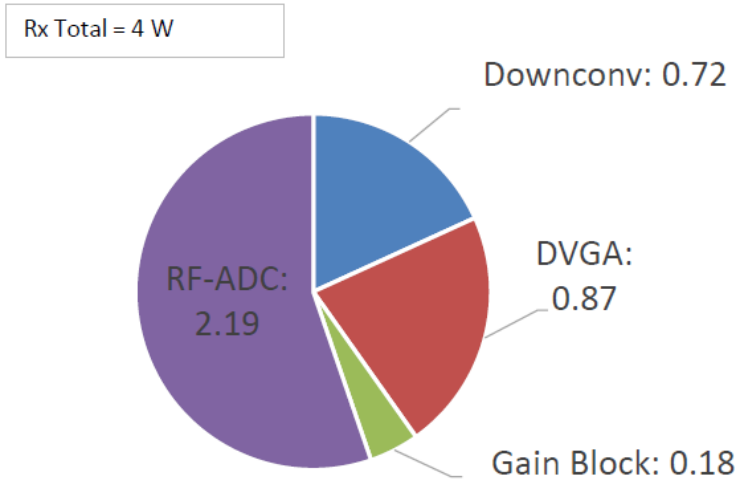
EIRP Budget	Typ	Units
Psat Final	39	dBm
Backoff	8	dB
Pave Final	31	dBm
Switch IL	1.5	dB
Filter IL	1.5	dB
Pave Antenna	28	dBm
Active Chains	10	
Pave Total	38.0	dBm
Antenna Gain	22	dBi
EIRP	60.0	dBm

10T10R: TGA2595-CP

DC Budget	Typ	Units
Pave Final	31	dBm
PAE at Backoff	8	%
Pdc/amp	15.7	W
Active Chains	10	
Pdc Total	157	W

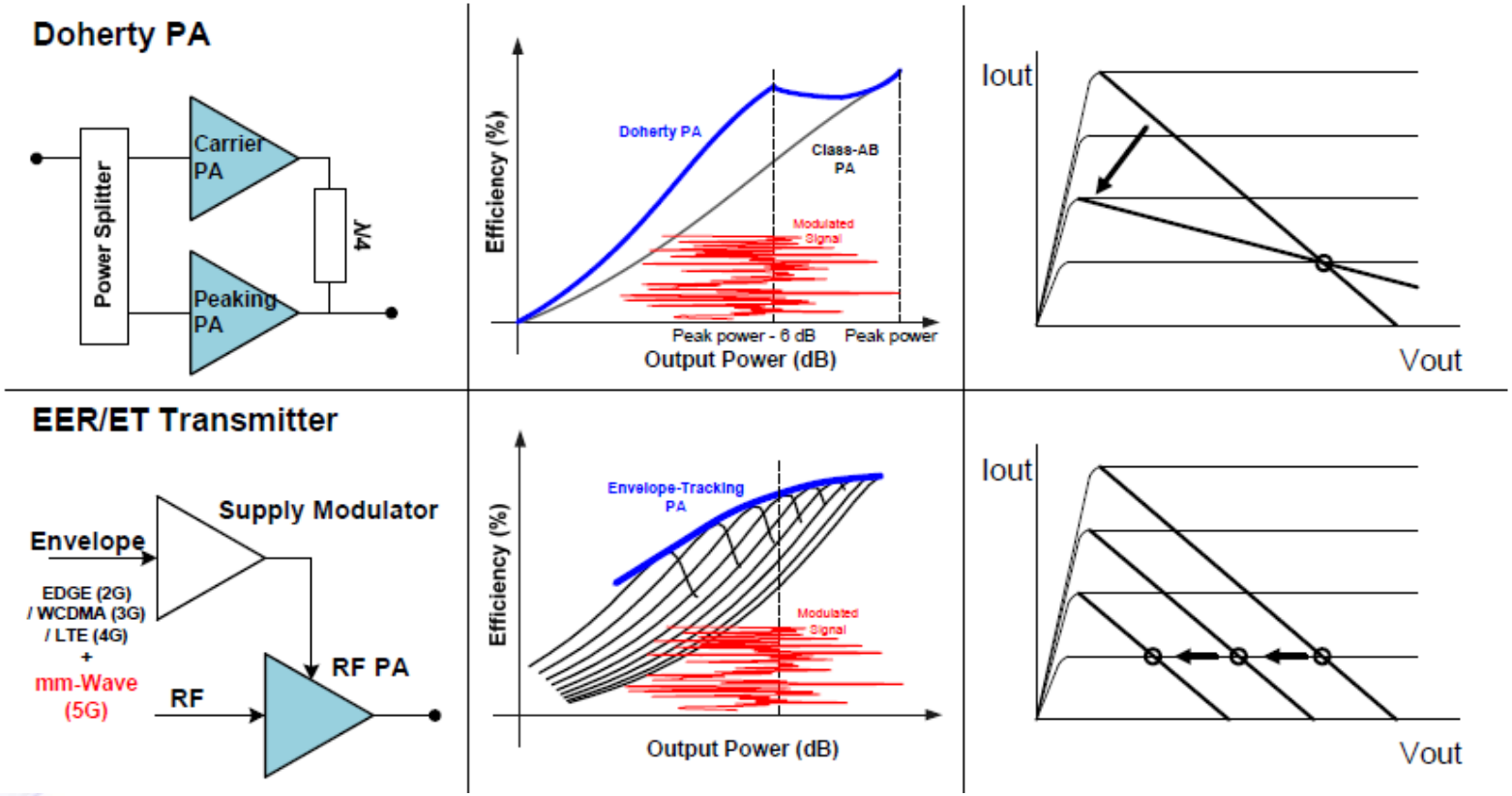
From Qorvo





大规模MIMO功放电路架构

- Doherty功放（DPA）电路架构信号带宽大、电路简单



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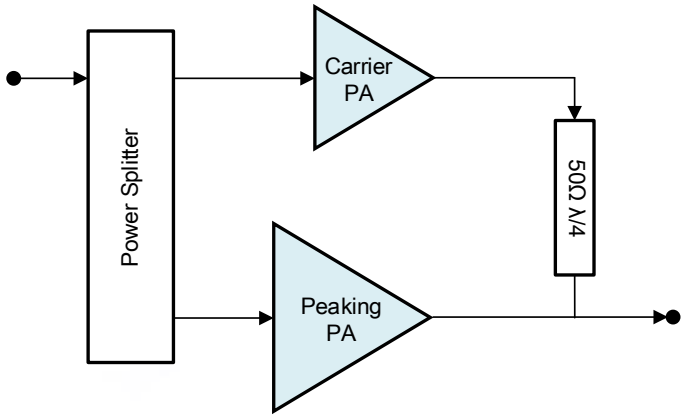
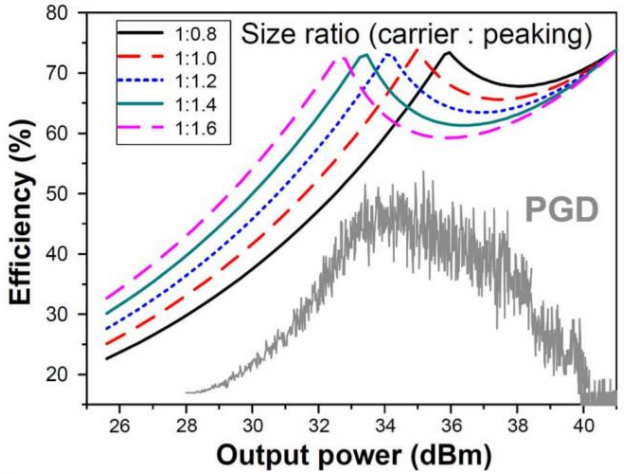
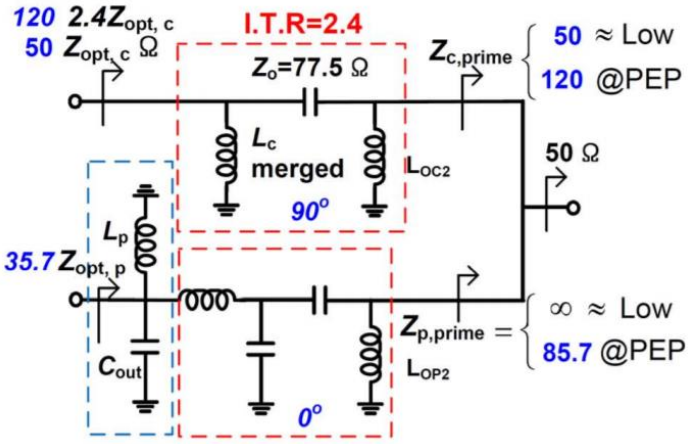
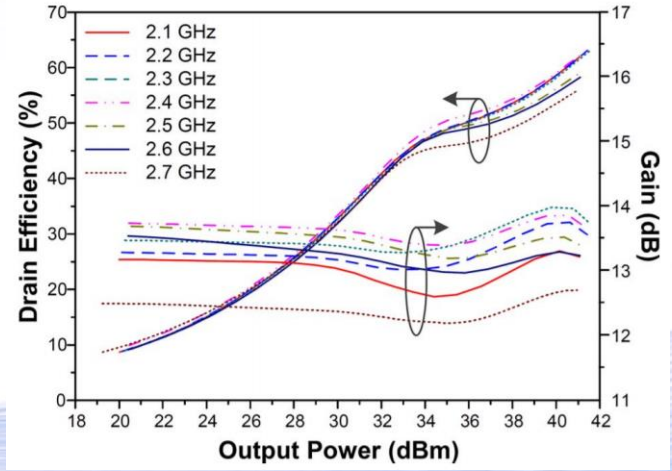
Sub-6GHz DPA电路架构

- 大规模MIMO发射机要求Doherty功放集成化封装
- 非对称、低Q值1/4阻抗变换线DPA电路



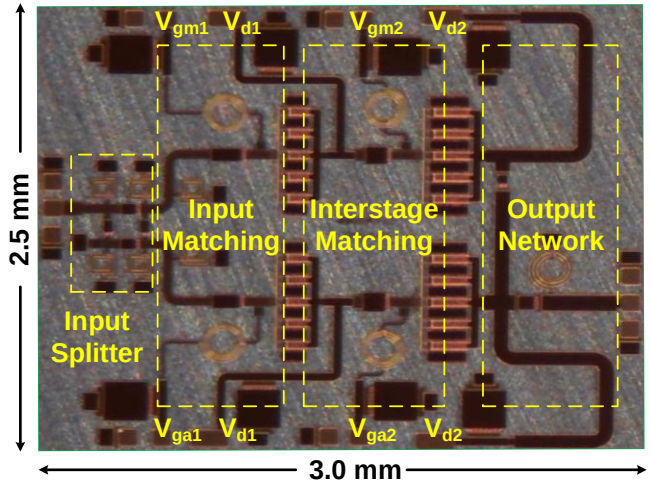


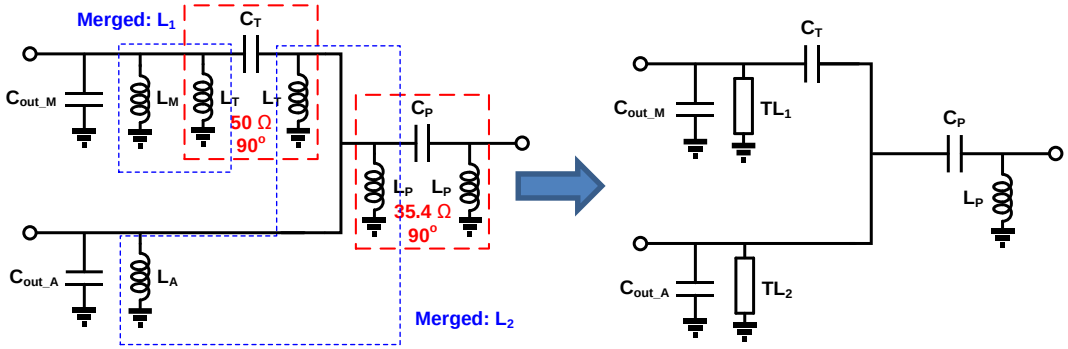




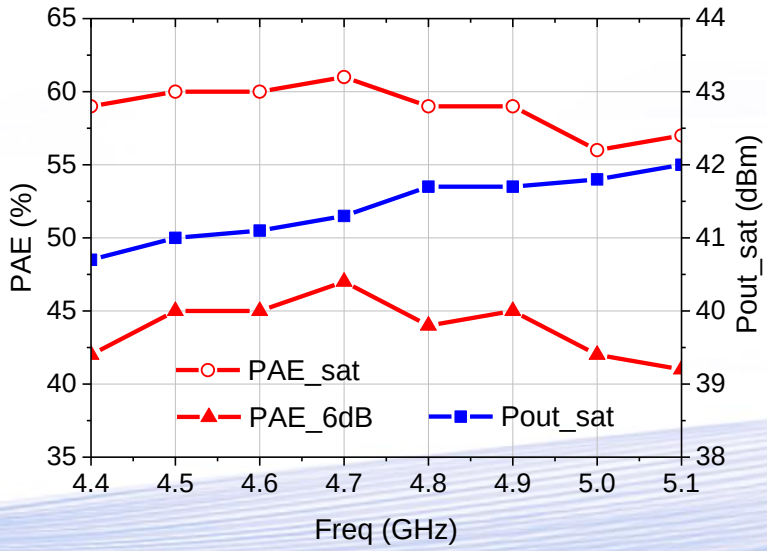
Sub-6GHz GaN全集成2-stage DPA

0.25um GaN





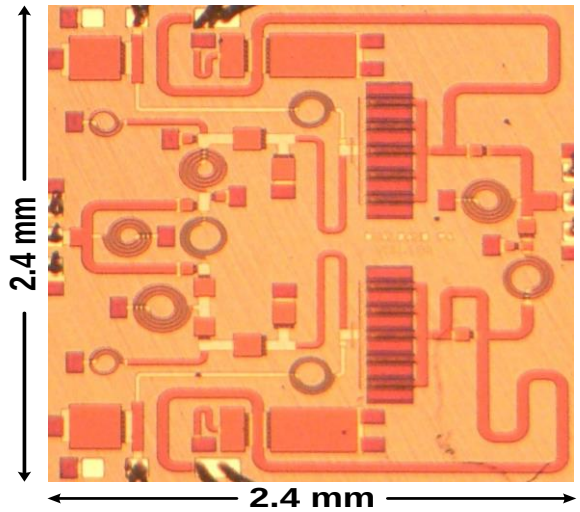
- DPA: 4.4~5.1 GHz
- Pout: 40.7~42 dBm
- Gain: > 17 dB
- PAE@peak: 57~62%
- PAE@backoff: 41~47%@6dB

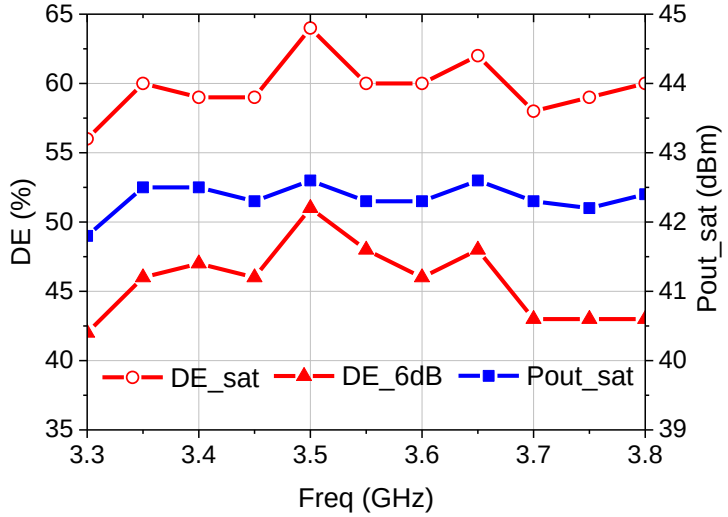


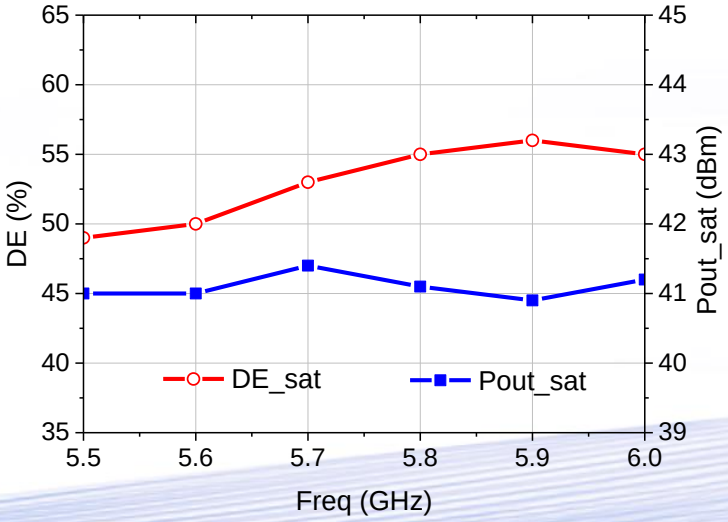
IEEE IMS 2019 (accepted)

Sub-6GHz GaN全集成双频（混合模式）

0.25um GaN



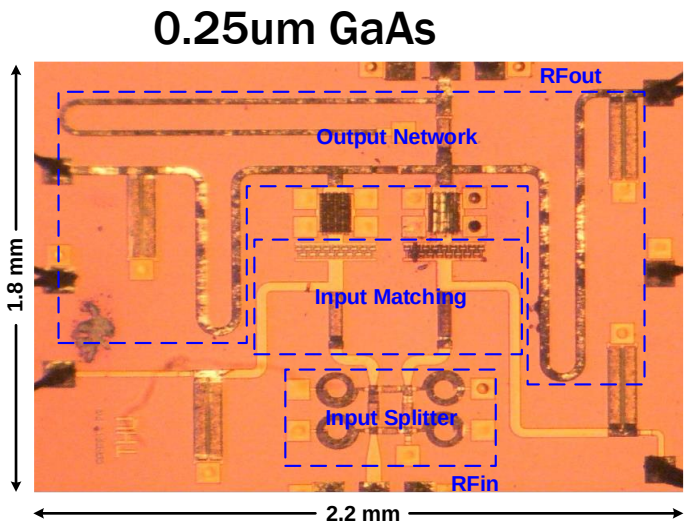


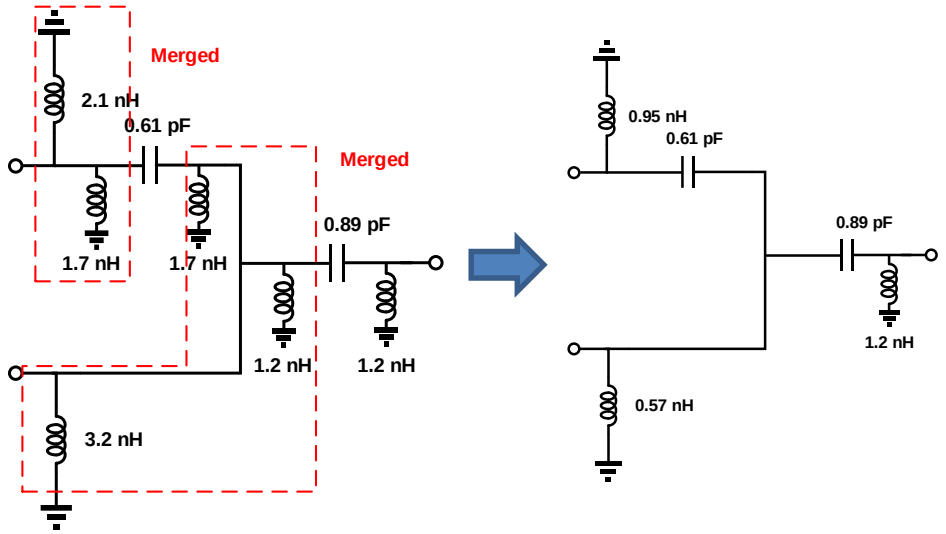


- DPA/AB: 3.3~3.8/5.5~6.0 GHz
- Pout: 42.6/42 dBm
- Gain: 12/10.5 dB
- PAE@peak: 56~64%/50~55%
- PAE@backoff: 42~51%@6dB/NA

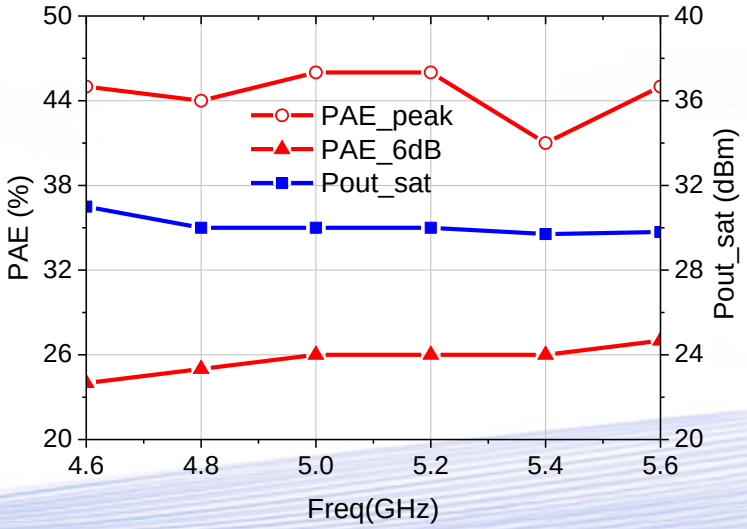
IEEE MWCL (published)

Sub-6GHz GaAs全集成DPA





- DPA: 4.6~5.6 GHz
- Pout: >30 dBm
- Gain: 11~15 dB
- PAE@peak: 41~46%
- PAE@backoff: 24~27%@6dB



IEEE MTT-S IMWS-5G (published)

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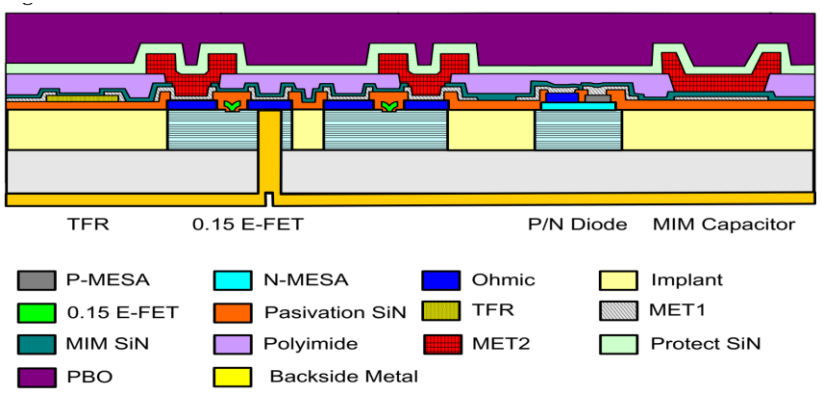
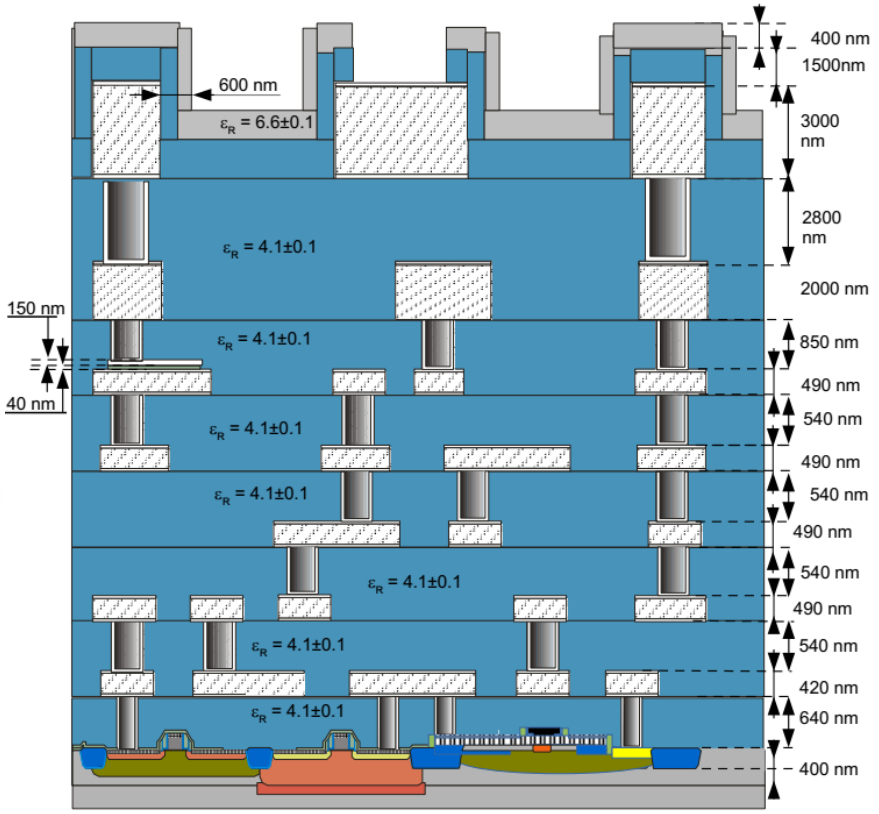
mmWave DPA工艺

- III-V化合物工艺：功率大、效率高、线性好、集成度低
- 硅基工艺：集成度高、功率较小，效率较低



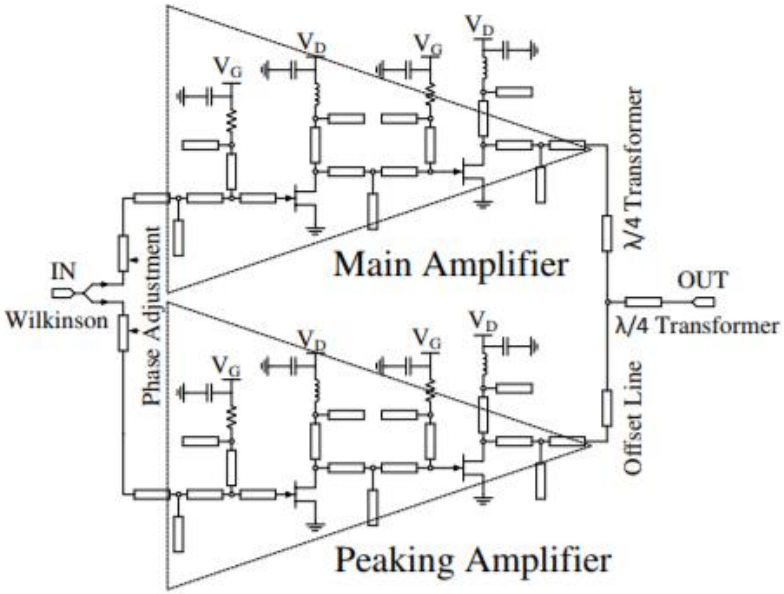
GaAs pHEMT

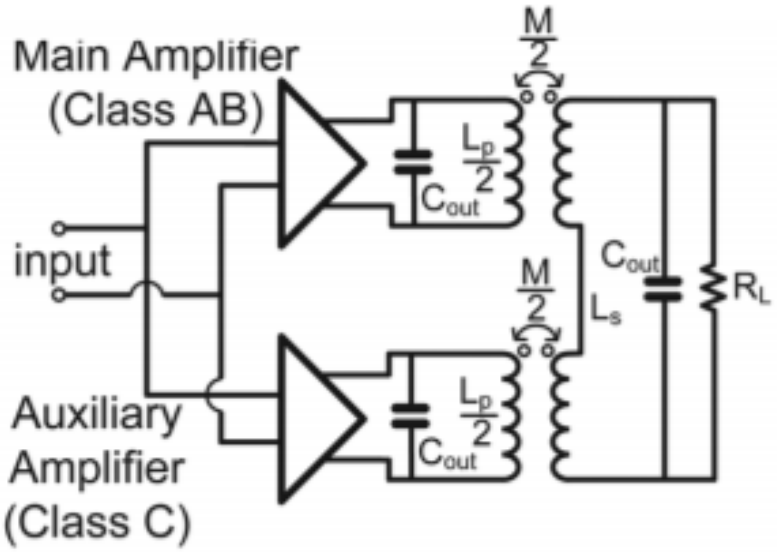


SiGe HBT

mmWave DPA电路架构

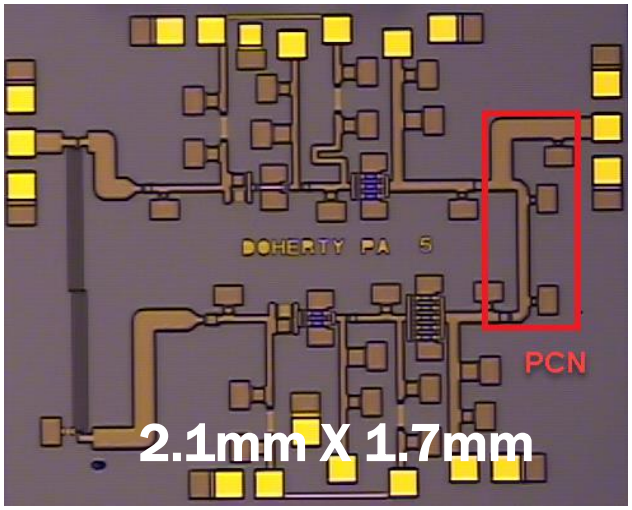
- 分布式传输线架构：金属层数较少工艺，芯片尺寸较大
- 变压器架构：适用多层金属工艺，芯片尺寸小

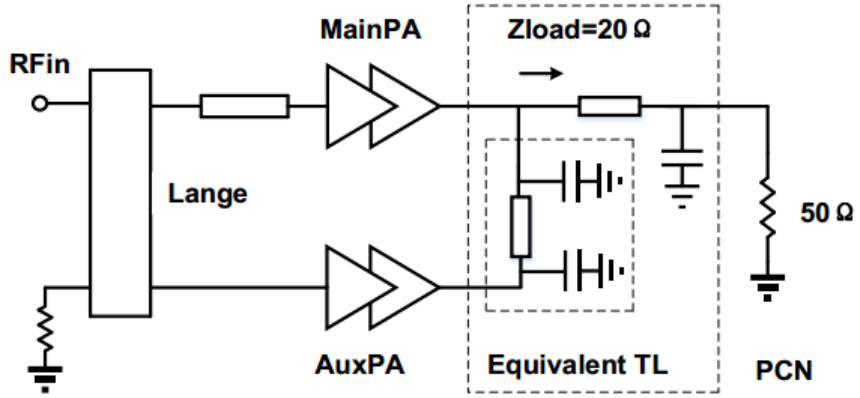




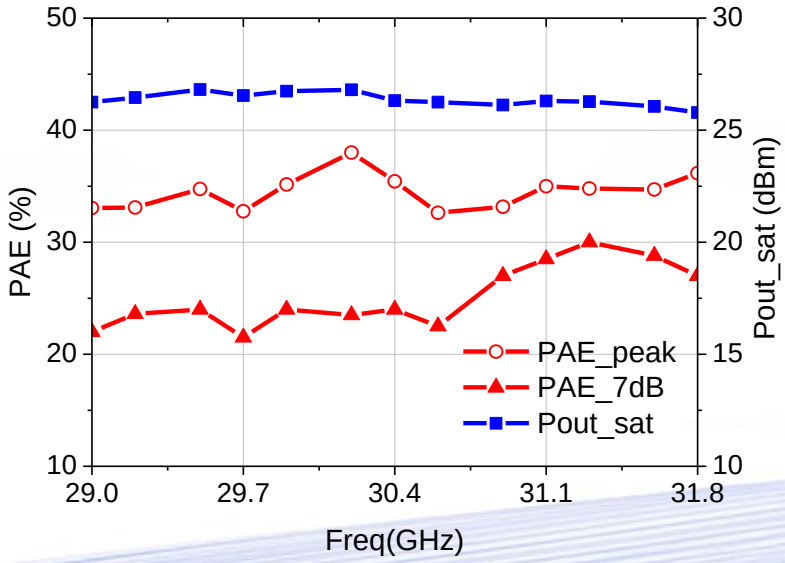
mmWave GaAs DPA设计

0.15um GaAs





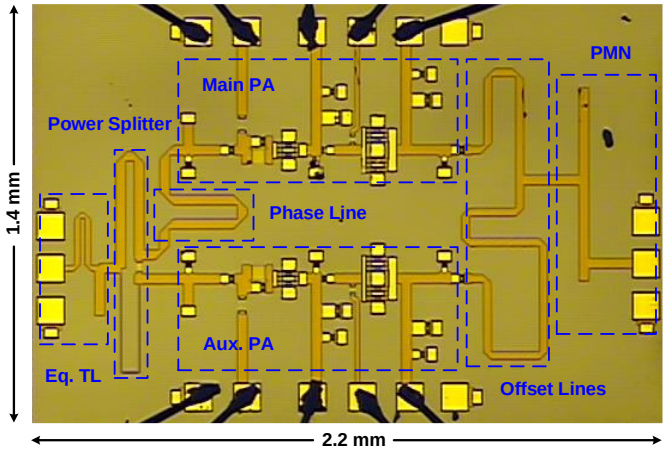
- DPA: 29~31.8GHz
- Pout: 25.7~26.8dBm
- Gain: 13~14dB
- PAE@peak: 31~38%
- PAE@backoff: 21~30%@7dB

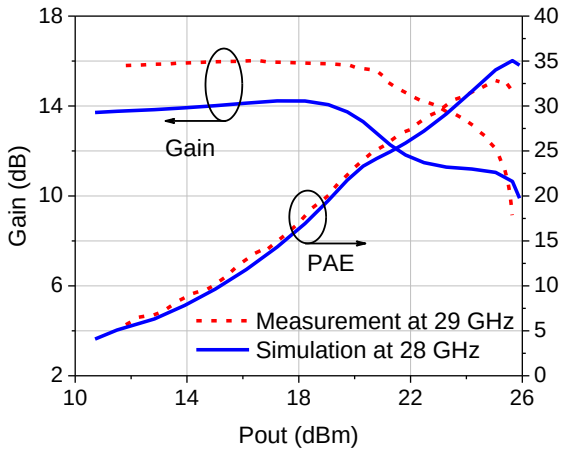


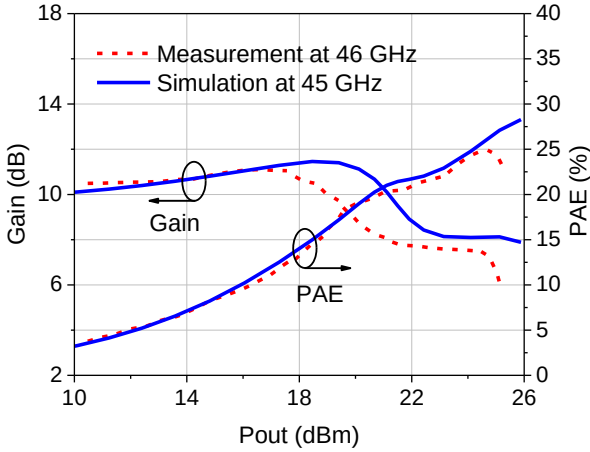
IEEE IMS 2018 (published)

mmWave GaAs双频DPA设计

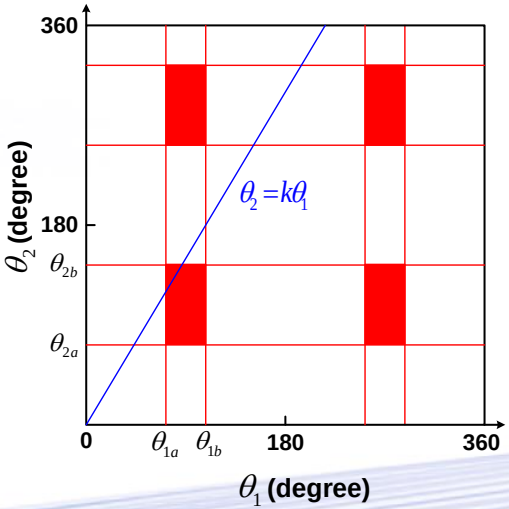
0.1um GaAs







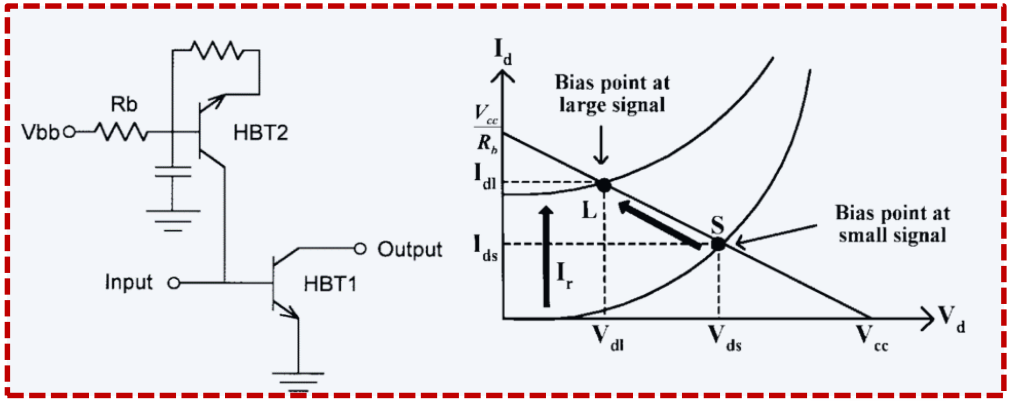
- DPA: 29/46 GHz
- Pout: 25.4/25.2 dBm
- Gain: 16/10.5 dB
- PAE@peak: 33%/25%
- PAE@backoff: 33%/25%@6dB

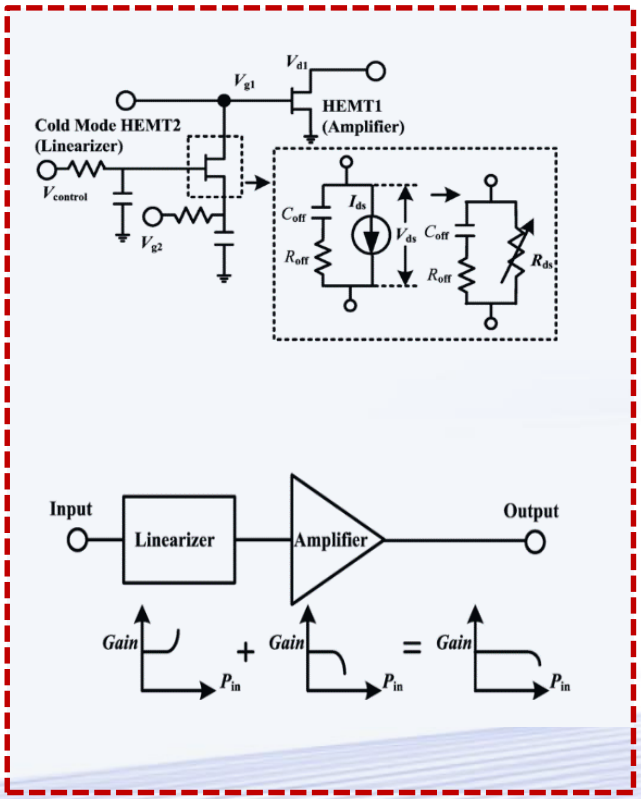


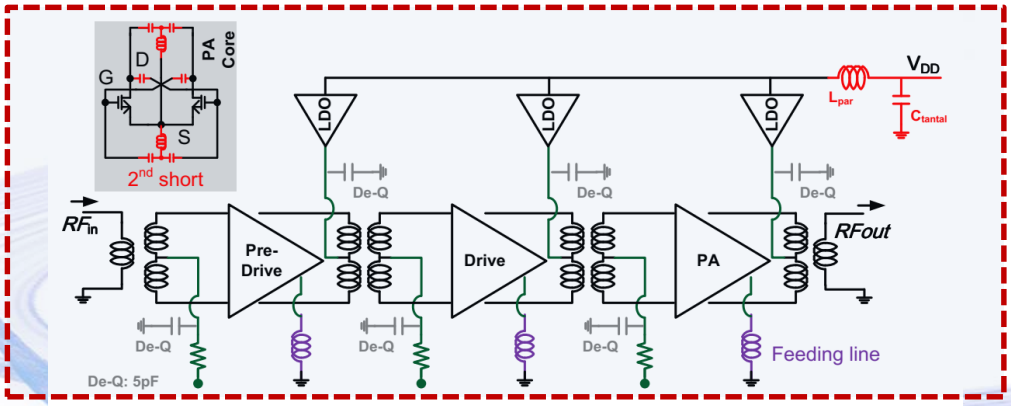
IEEE T-MTT 5G special issue (accepted)

mmWave DPA线性化设计

- 自适应偏置电压
- 视频带宽扩展
- 预失真补偿

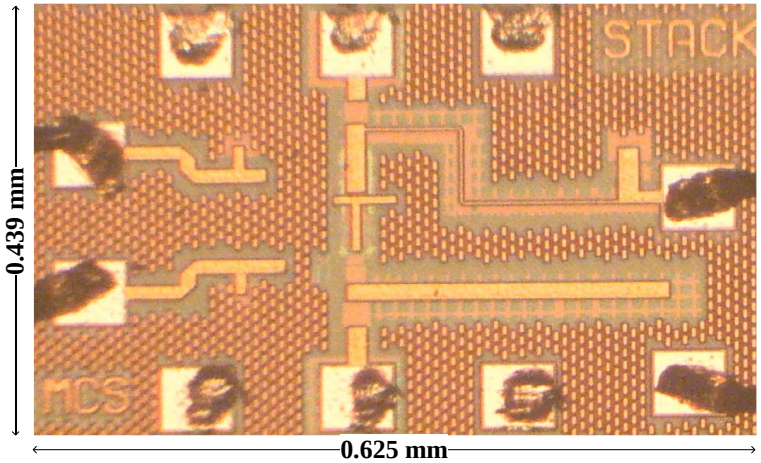


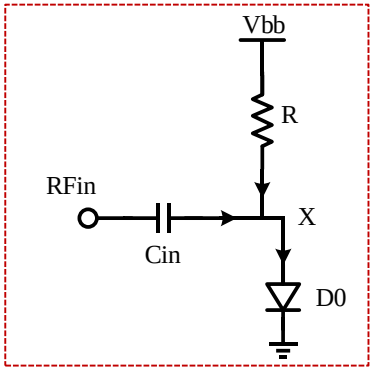


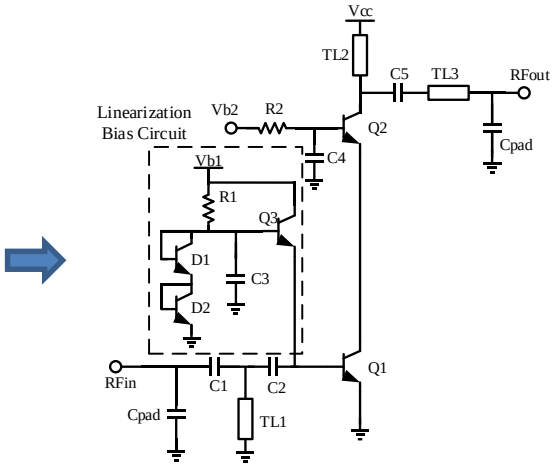


mmWave SiGe Class-AB高线性化设计

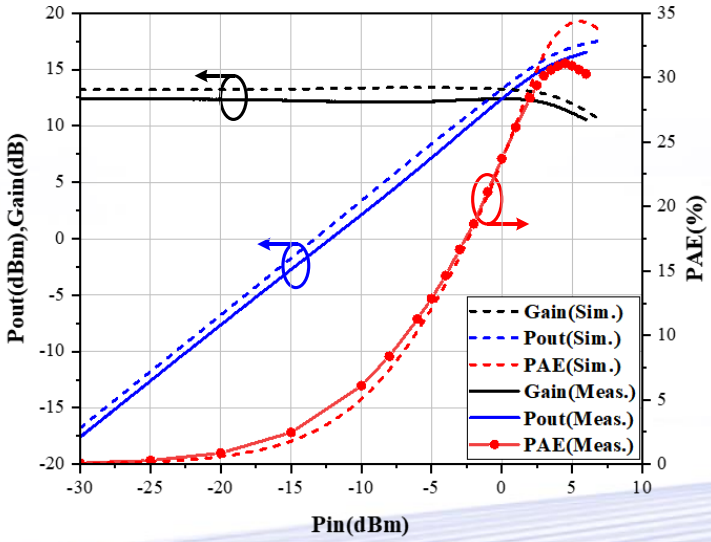
0.25um SiGe







- Class-AB: 28 GHz
- Pout: 16.5 dBm
- Gain: 12.5 dB
- PAE@peak: 31.1%
- EVM: 3.32%(800MHz 64QAM)



IEEE IMS 2019 (accepted)

Intelligent Microwave Circuit and System Lab

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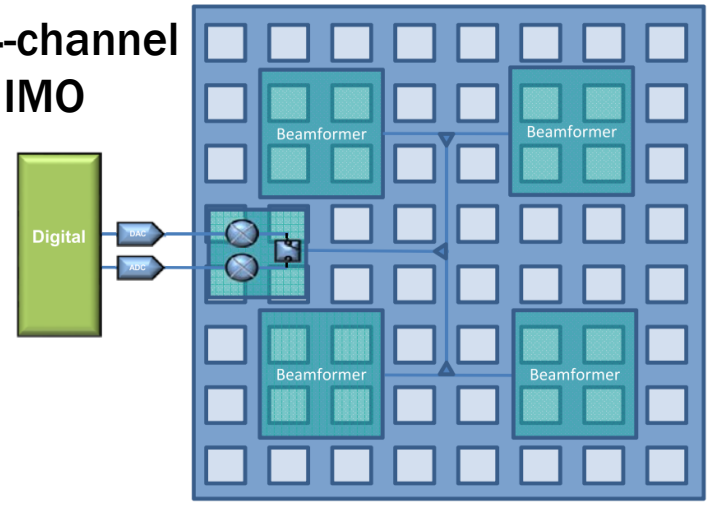
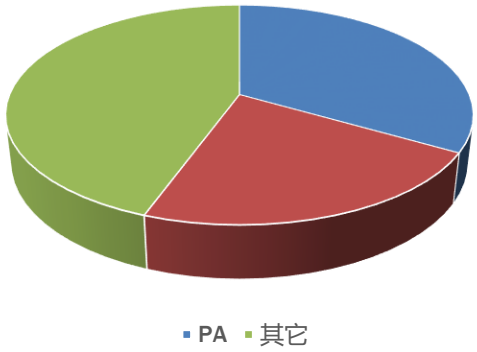
大规模MIMO功放效率线性挑战

3.5GHz 64-channel
Massive MIMO

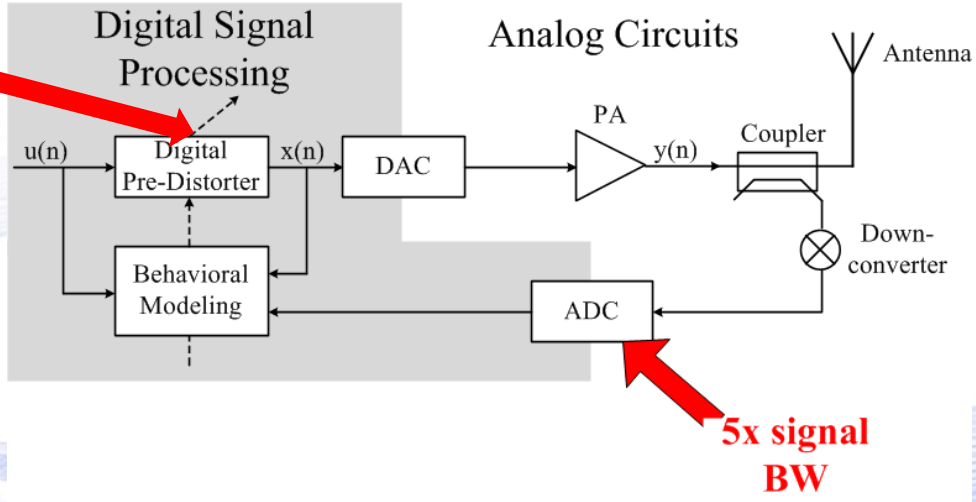


发射机功耗>1300W



5x signal
BW

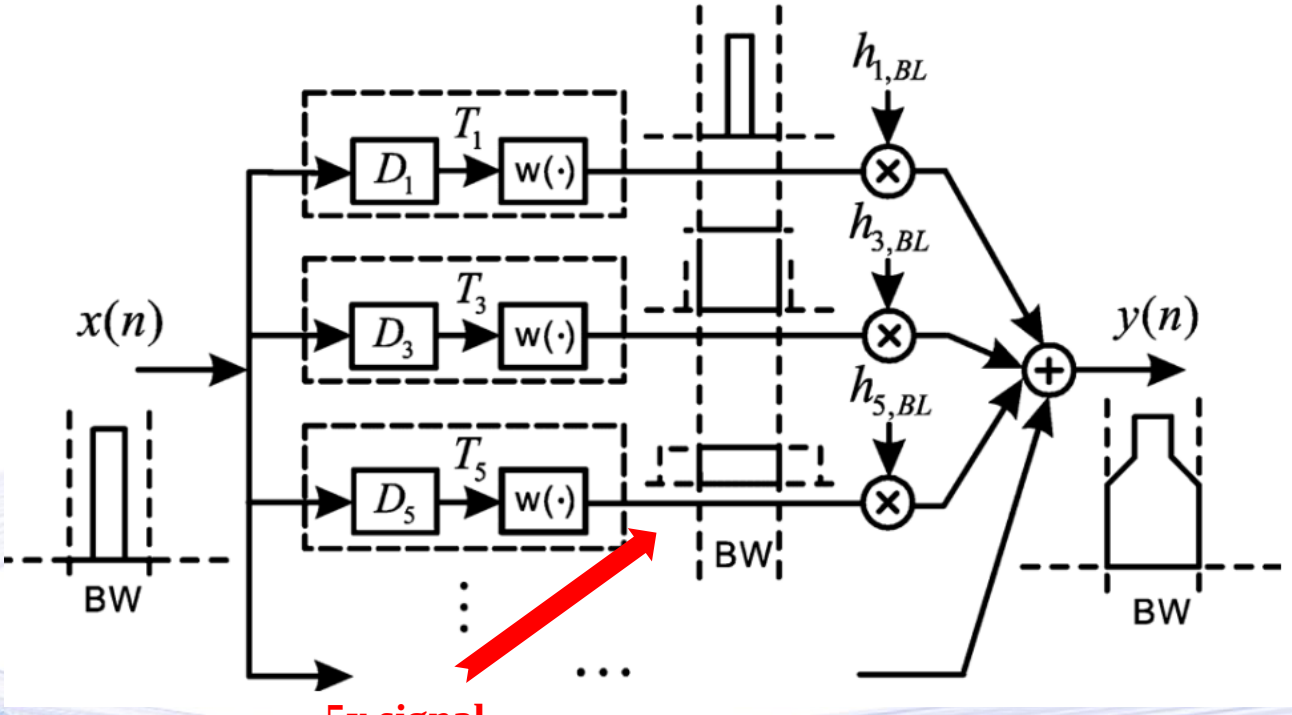
如何降低功耗？？



Subsampling
method

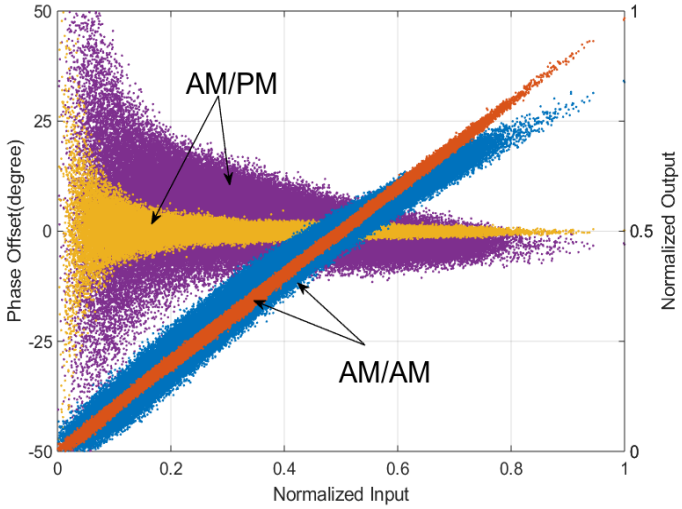
带宽压缩DPD补偿技术

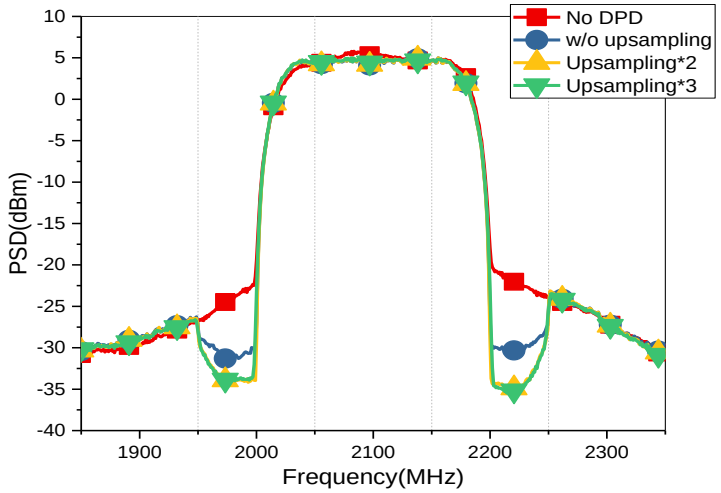
- 传统带限DPD方法虽然可以降低发射带宽，但仍需先产生宽带补偿信号再进行滤波；
- 宽带DPD补偿算法需要非常高的时钟频率，FPGA单元的处理功耗显著上升。



带宽压缩DPD测试结果

- 采用升采样-滤波带限-降采样的方式，牺牲少部分复杂度换取较高的精度。





载波频率：2.1GHz

信号：200MHz带宽，64QAM调制，峰均比7.5dB

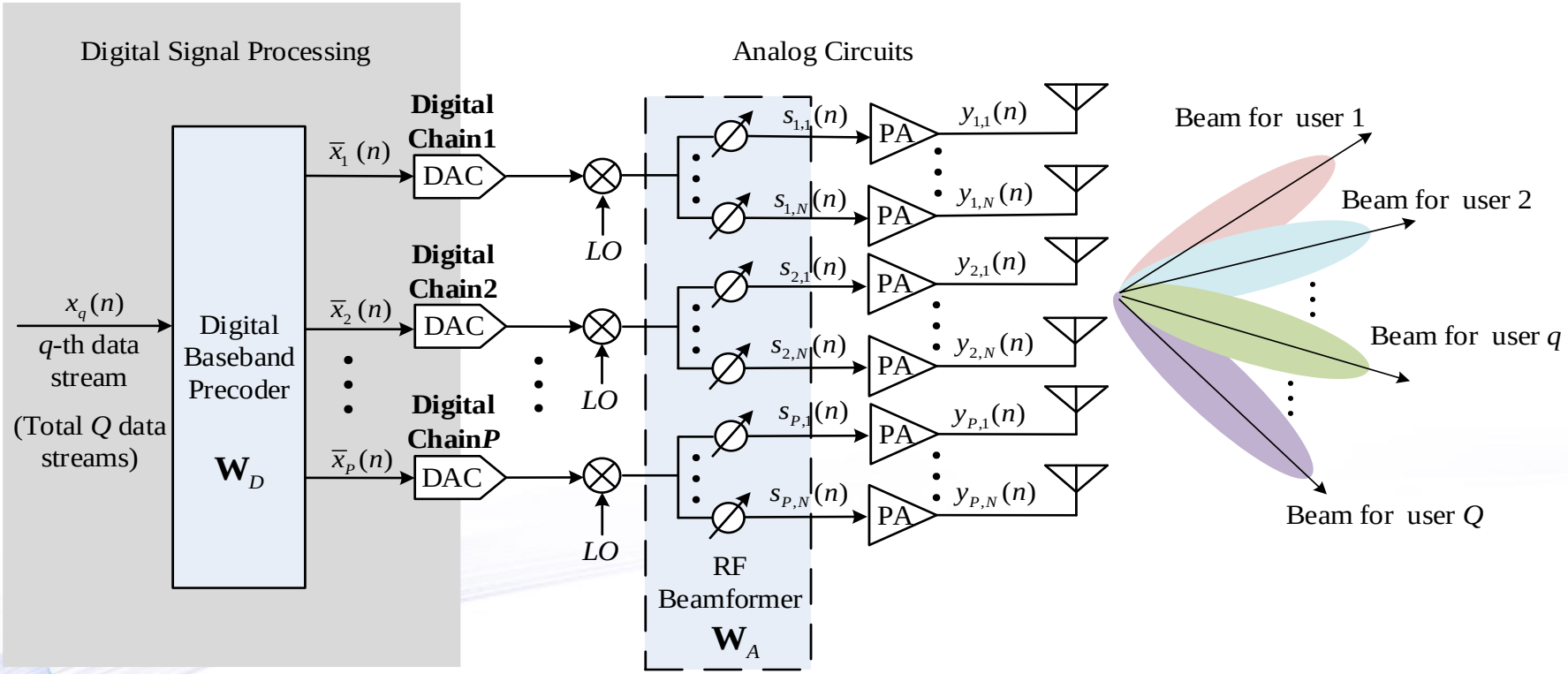
采样率：320Msps(Q=1)

	NMSE(dB)	EVM(%)
w/o DPD	-23.07	6.88
w/ DPD (Q=1)	-34.63	2.05
w/ DPD (Q=2)	-37.44	0.85

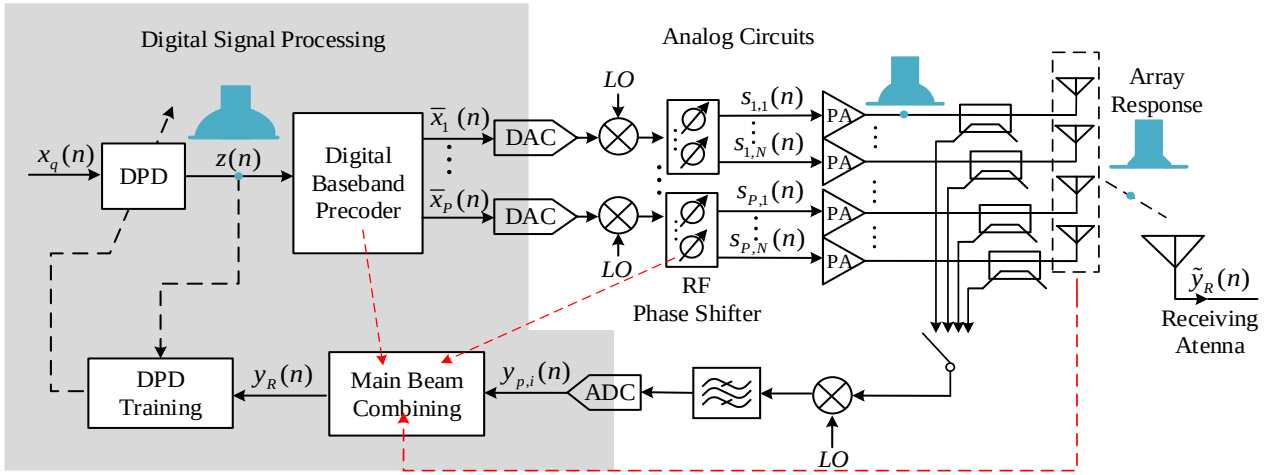
IEEE MWCL (under revision)

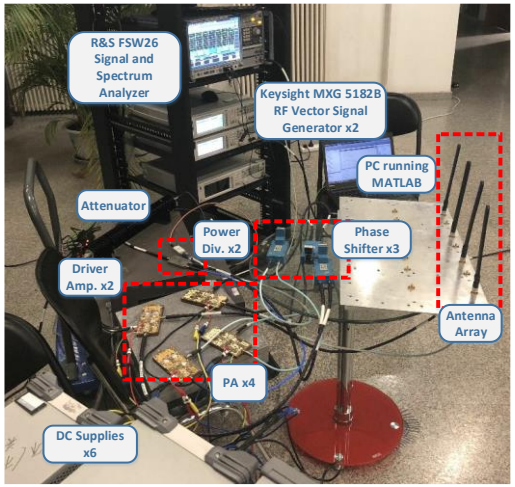
混合波束成形DPD

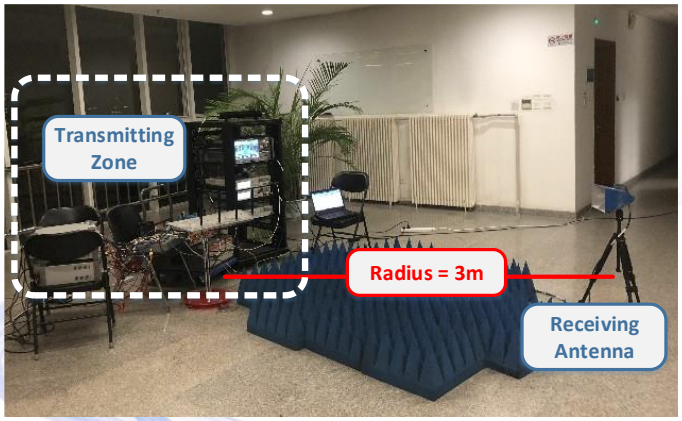
- 以波束为对象进行非线性建模和补偿

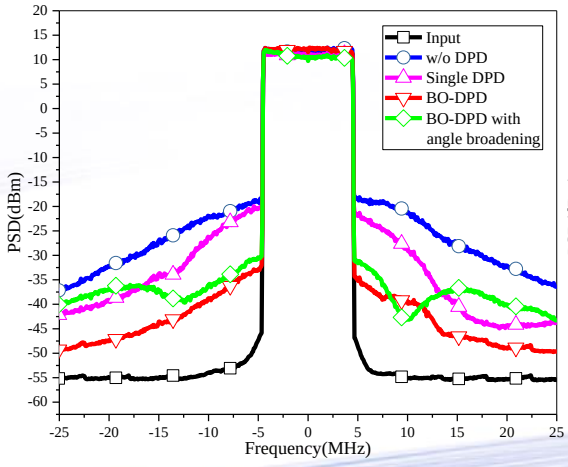


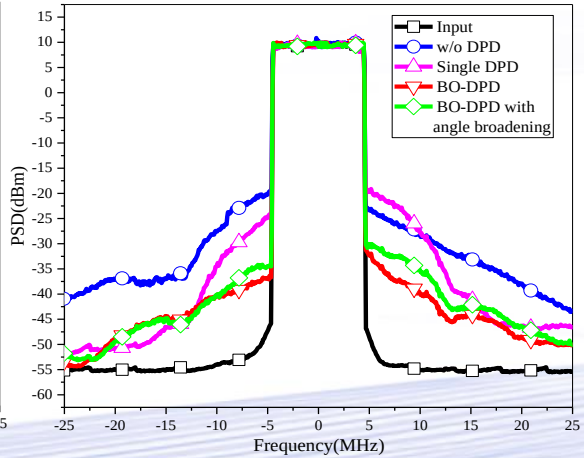
混合波束成形DPD测试











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汇报内容

一、5G大规模MIMO功放需求

二、Sub-6GHz Doherty功放设计

三、mmWave Doherty功放设计

四、大规模MIMO功放线性化

五、总结与展望

总结与展望

- 混合集成DPA在Sub-6GHz具有性能和成本上优势，需要进一步研究消除记忆效应方法；
- mmWave III-V化合物和硅基DPA在不同场景中都有应用需求，需要进一步提升线性化设计技术；
- 在大规模MIMO数字波束成形发射机中，需要进一步研究低带宽DPD补偿技术，降低DPD单元功耗。

感谢聆听

欢迎各位批评与指正！

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